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Testing and Evaluation of Zinc-Iron and Zinc-Nickel-Tin Coatings on Test Panels

by Marc Pepi and Russell Kilbane

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Testing and Evaluation of Zinc-Iron and Zinc-Nickel-Tin Coatings on Test Panels

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Abstract

Testing and evaluation were conducted on two zinc alloy coatings (zinc-iron and zinc-tin-nickel) applied to test panels. Testing included current potential, adhesion, and salt fog testing. The appearance, coating thickness, and metallography of the coatings were also assessed. Each of the coatings was able to withstand over 1000 hr of salt fog testing without the formation of substrate corrosion.

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1. Background

Two coatings were tested and evaluated (Table 1) by the U.S. Army Research Laboratory (ARL) for possible inclusion in the "Cadmium Replacements for Defense Systems" program [1], managed by Dr. Michael J. Kane of the Research and Engineering Group of the Naval Air Systems Command, Patuxent River, MD. Two zinc alloy coatings were tested—zinc-iron electroplating and zinc-nickel-tin electroplating. The appearance and coating thickness of each coating was observed in the as-received condition, followed by these tests: current potential, adhesion, salt fog resistance and metallographic examination. The salt fog resistance of the zinc-iron coating was previously evaluated by the Materials Analysis Group of the Processing and Properties Branch (PPB) in an earlier study [2] and was found to produce no coating or base metal corrosion after 1000 hr. It is widely documented that the zinc-iron coating can resist base metal corrosion for up to 1000 hr of salt fog exposure, as was verified by PPB testing. The AISI 4130 steel panels used in this study (as well as the previous zinc-iron plating) were coated by Westfield Electroplating Co. (WEPCO), Westfield, MA.

Table 1. Coatings tested by ARL in this study.

Coating	Quantity of Panels	Source	Salt Fog	Nominal Thickness (inch)
Zinc-Iron	1	Westfield electroplating	480 hr[a]	0.0005 – 0.0010
Zinc-Nickel-Tin	3	Westfield electroplating	1000 hr[b]	0.0005[c]

[a] Per specification ASTM B 842 [3], Class A, Type 1, Grade 2.
[b] Suggested by manufacturer.
[c] Target thickness.

2. Coatings

A zinc-iron coating was applied to a panel in accordance with ASTM B 842 [3], as a Class 1 (99% zinc, 1% iron), Type A (with a black chromate conversion coating), Grade 2 (12 μ in nominal thickness) coating offering 480 hr of salt fog corrosion protection. The purpose of this panel was solely for determining the current potential and metallography, since the adhesion and salt fog testing had already been performed. The zinc-nickel-tin coating is a WEPCO-proprietary coating, which purportedly can endure 1000 hr of salt fog exposure. It basically consists of a zinc-nickel base coat, followed by a topcoat of tin. It should be

noted that at high temperatures (>150 °F), there is evidence that zinc alloy coatings become noble (rather than sacrificial), leading to steel corrosion [4]. This should be kept in mind when considering these alloys for high-temperature applications.

3. Appearance

Figure 1 shows the zinc-iron panel in the as-received condition. The coating was very uniform in both color and coverage and was shiny and smooth in appearance. The coating was black from the supplementary black chromate treatment. A representative zinc-nickel-tin coated panel is shown in Figure 2 in the as-received condition. This coating was gray in color and showed some evidence of spotting, streaking, and scratches (as shown in the figure).

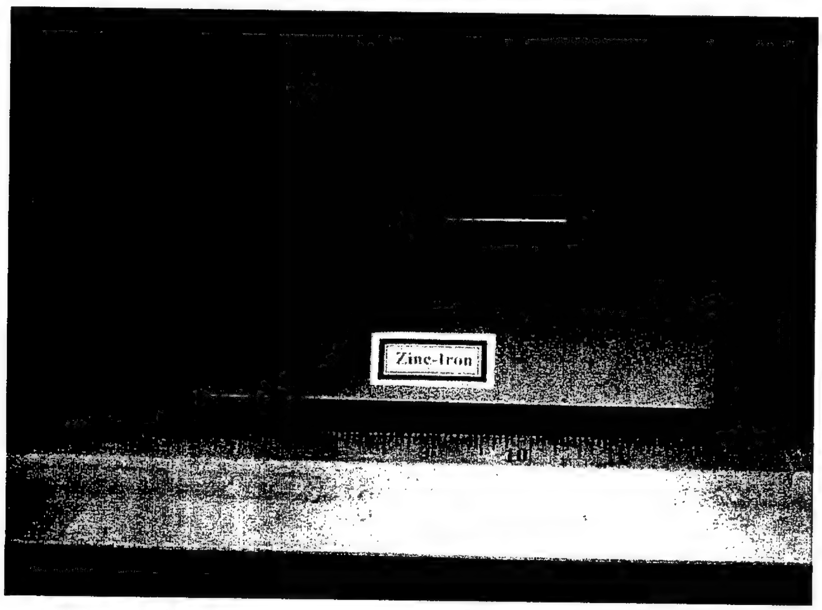

Figure 1. Zinc-iron coated panel in the as-received condition (reduced ~50%).

4. Thickness

The thickness of each of the coatings was measured nondestructively prior to testing. A Positector 2000 instrument was calibrated using a 1-mil shim (tolerance ± 0.0002-in) prior to testing. Five different readings were taken on the regions shown in the schematic (Figure 3). The average of five readings is listed in Table 2.

Figure 2. Two zinc-nickel-tin coated panels prior to salt fog testing (reduced ~50%).

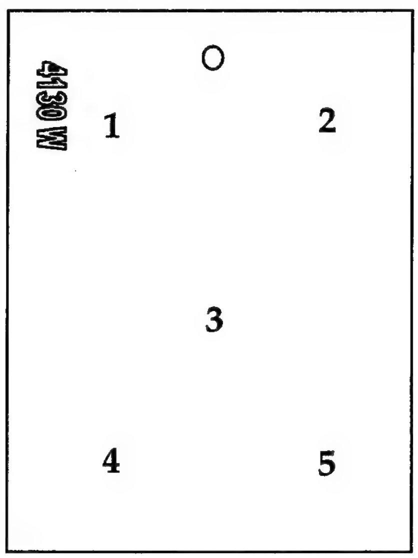

Figure 3. Location of coating thickness measurements on top face of panels (exposed surface).

Table 2. Coating thickness measurements.

Panel	Average Thickness From Five Readings (inch)	Nominal Thickness (inch)
Zinc-Iron	0.00068	0.0005–0.0010
Zinc-Nickel-Tin #1	0.00054	0.0005[a]
Zinc-Nickel-Tin #2	0.00048	0.0005[a]
Zinc-Nickel-Tin #3	0.00058	0.0005[a]

[a]Target thickness.

5. Current Potential

The current potential of the zinc-iron panel and one of the zinc-nickel-tin panels was measured using the open circuit potential technique. Testing was performed in a 3.5% solution of NaCl against a saturated calomel electrode (SCE). This test setup consists of mercurous chloride (calomel), Hg_2Cl_2, mixed in a mercury paste on a pool of liquid mercury in contact with a saturated KCl solution [5]. Electrical contact is made when an inert platinum wire is immersed into the mercury. This test is used as a basis for a galvanic series for seawater [6]. The results of this analysis are listed in Table 3. As shown, the current potential of zinc-iron is similar to published values for zinc electroplating, whereas the zinc-nickel-tin potential is closer to that of published values for cadmium electroplating.

Table 3. Open circuit potentials of alternative coatings compared with cadmium and zinc.

Panel	Current Potential
Zinc-Iron	-1.02
Zinc-Nickel-Tin	-0.63
Zinc [7]	-1.10
Cadmium [7]	-0.80

6. Adhesion

The adhesion of each coating was assessed by scribing a line with a knife through the coating down to the base metal. At a magnification of 10×, no separation between the coatings and the substrates was observed. In addition, there was no evidence of flaking, peeling, or blistering as a result of the scribe mark. These scribes were used for the salt fog testing for observing possible base metal corrosion. The adhesion was deemed satisfactory as a result of this testing.

7. Salt Fog Testing/Results

Two of the zinc-nickel-tin plated panels were salt fog tested in accordance with ASTM B 117 [8]. The parts were subjected to a 5% salt fog environment and were supported such that they were approximately 15° from the vertical, as required. The panels were continually monitored, up until the end of testing. The zinc-nickel-tin plated panels were subjected to 1400 hr of salt fog exposure. Sacrificial corrosion of the coating ensured that there were no base metal red corrosion products at the end of the exposure. The red stains noted on the edge of the panel were actually drippings from a sample adjacent to it within the chamber. Compare Figures 2 and 4, which show detailed photographs of a zinc-nickel-tin panel before salt fog and after 1400 hr of salt fog exposure. Note that there was no red corrosion at the scribe of either panel.

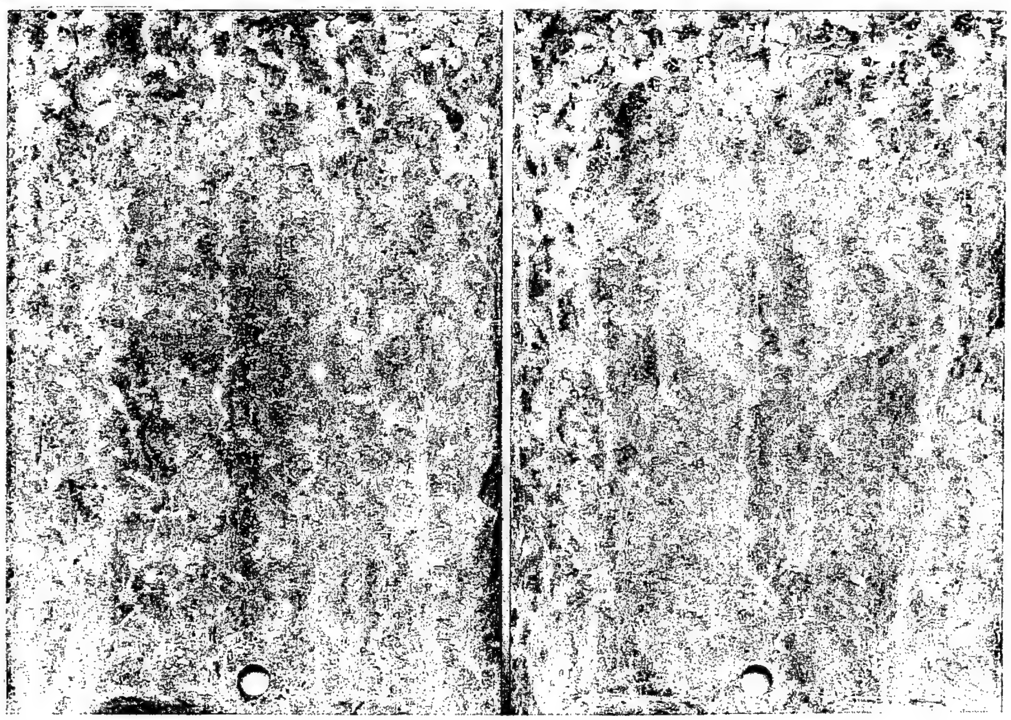

Figure 4. The two zinc-nickel-tin coated panels after 1400 hr of salt fog exposure. The red corrosion at the edges was a result of adjacent test panel dripping (reduced ~35%).

8. Coating Salt Fog Requirements

The salt fog requirements for the zinc-iron coating, as dictated by the governing specification ASTM B 842 [3], are listed in Table 4. The zinc-iron plating exceeded the requirement listed below, by withstanding over 1000 hr of salt fog corrosion with no base metal corrosion. Since the zinc-nickel-tin plating is not governed by a specification, it does not have a similar requirement. Therefore, this testing was performed for observational purposes. As a result of this test, it can be stated that the zinc-nickel-tin coating protected the base metal after 1400 hr of salt fog exposure, without evidence of red corrosion products.

Table 4. Coating salt fog requirements.

Coating	Specification	Corrosion Requirement
Zinc-Iron	ASTM B 842 [3], Class A, Type 1, Grade 2	"The coatings shall show no zinc alloy corrosion after 144-hours or base metal corrosion after 480-hours" [3].
Zinc-Nickel-Tin	Proprietary	N/A

9. Metallography

A sample of each coated panel was subjected to metallographic preparation to examine the uniformity and integrity of each coating. The samples were sectioned from the panels using a precision wafering diamond saw to minimize damage to the coatings. The samples were rough polished using silicon carbide paper ranging in grit size from 240 to 1200. Final polishing was performed using 1-μ diamond, followed by 0.25-μ alumina. Figure 5 shows the zinc iron plating to be uniform in thickness. Figure 6 shows a cross section of the zinc-nickel-tin plating. Note the two coating layers present—the zinc-nickel base coat followed by the tin topcoat. The photomicrograph reveals what appear to be cracks in the base coat and defines grains within the topcoat. Figure 7 shows the ability of the zinc-nickel-tin plating to deposit on sharp corners, with relative uniformity. There were some areas that showed what appeared to be inclusions and cavities within the tin topcoat of the zinc-nickel-tin coating, as shown in Figure 8. Based on the salt fog results, these anomalies did not affect the integrity of the coating.

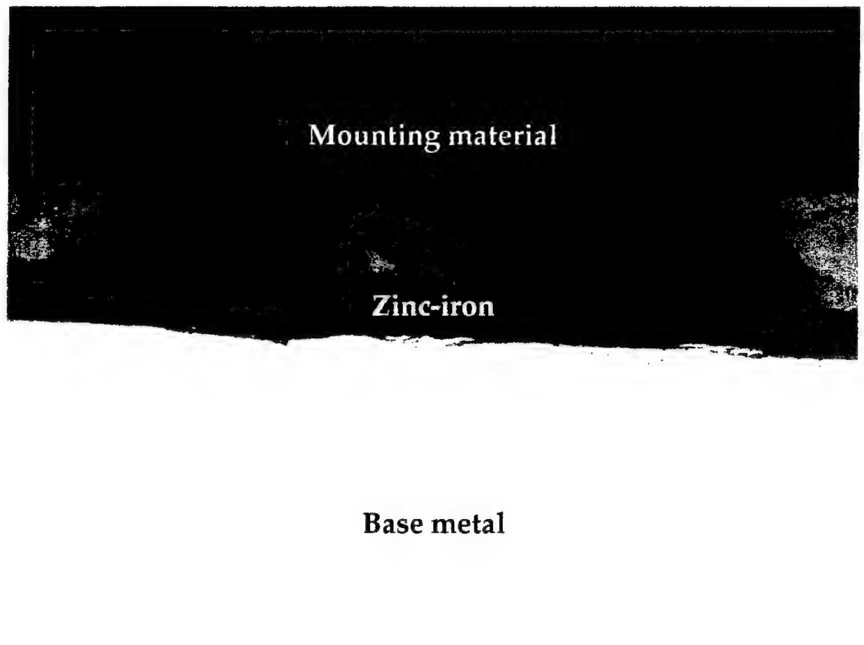

Figure 5. Cross section of the zinc-iron coating showing the thickness uniformity (magnification 400×).

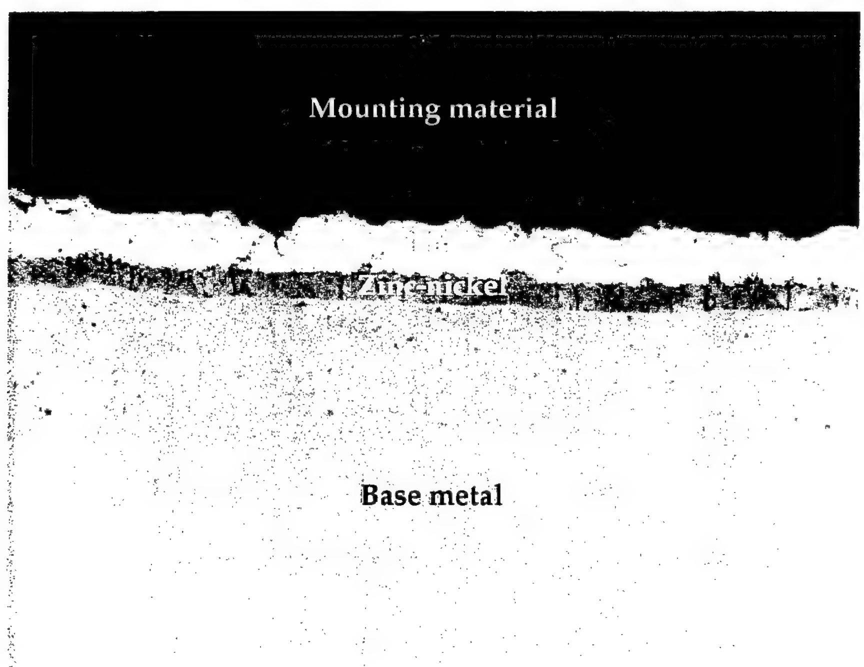

Figure 6. Cross section of the zinc-nickel-tin coating showing two distinct layers. Note the cracked zinc-nickel base coat and the structure within the tin topcoat (magnification 400×).

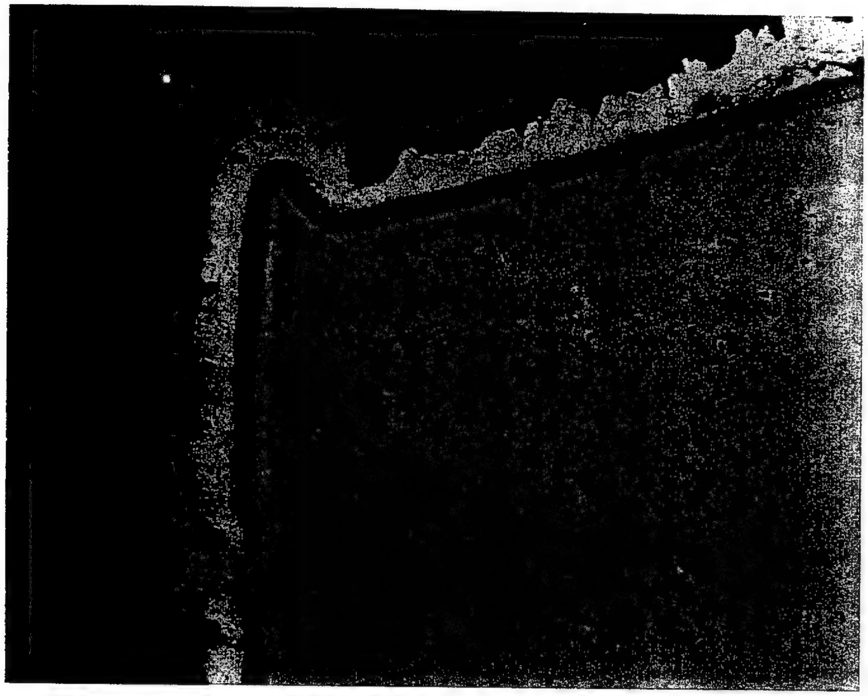

Figure 7. Cross section of the zinc-nickel-tin coating showing the ability of the coating to adhere around sharp corners (magnification 200×).

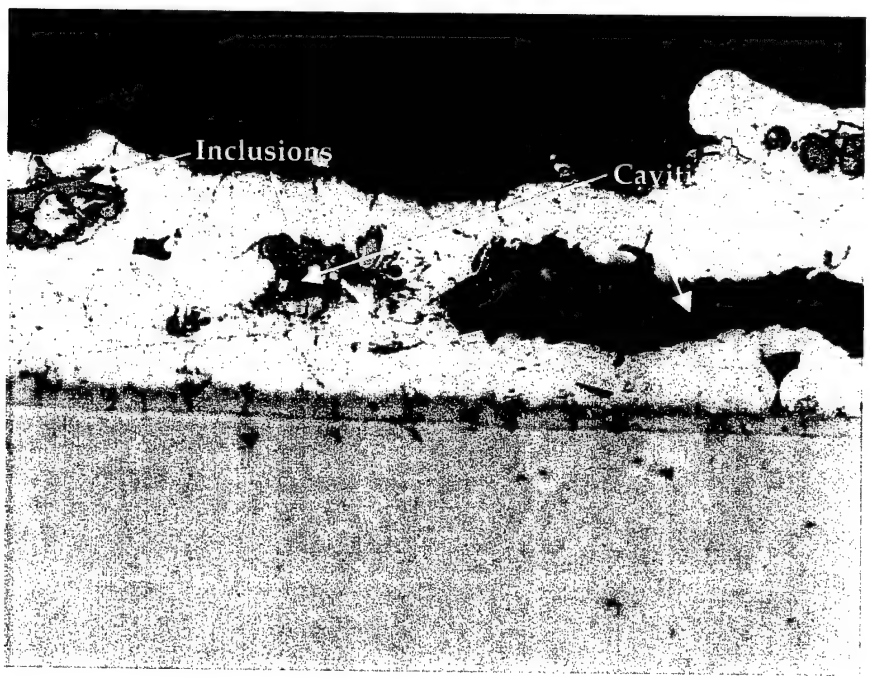

Figure 8. Cross section of another area of the zinc-nickel-tin coating showing inclusions and cavities within the tin layer; the coating was thicker in this region (magnification 400×).

10. Conclusion

Both of these coatings were acceptable with respect to the cursory testing (adhesion, salt fog resistance) performed within the context of this report. The current potential of the zinc-nickel-tin makes it more appealing as a replacement for cadmium than the zinc-iron. However, before a final assessment can be made, the following testing should be performed, as a minimum, on these coatings to ensure functional performance of the alternative in fastener applications: torque-tension testing, galling testing, paint adhesion testing, and operational chemical compatibility testing. Also, as previously mentioned, caution should be exercised when considering zinc-alloy coatings for high-temperature applications (>150 °F).

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